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Temperature Sensitivity of Aircraft Cannon Propellants

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BALLISTICS BRANCH
DIRECT FIRE WEAPONS DIVISION

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The temperature sensitivity of a number of double-base ball and rolled ball, extruded double base, triple base, nitramine and some highly plasticized extruded aircraft cannon propellants have been evaluated in the 20-mm, 27-mm, and 30-mm guns. The 20-mm ball and rolled ball propellants, the 30-mm rolled ball propellants, the triple base and nitramine 30-mm propellants and the 27-mm propellant all show evidence of anomalously low piezometric efficiencies at low temperatures which can be attributed to brittle grain fracture. At higher temperatures, the rolled ball propellants show evidence of unusually high piezometric efficiencies and, in

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particular, show a pronounced ballistic insensitivity to temperature effects. Such insensitivity results from severe low temperature brittle grain fracture with a lesser and diminishing degree of fracture at ambient temperature and above, until at high temperature the increased plasticity of the propellant material resists grain fracture. Another mechanism which can induce anomalously low and high piezometric efficiencies at high temperatures involves a physical softening of the propellant material. This mechanism can be expected to give anomalous high temperature ballistics for highly plasticized gun propellants.

PREFACE

This report documents work performed at the Air Force Armament Laboratory, Armament Division, Eglin Air Force Base, Florida between March 1982 and June 1982.

Dr. Clifford W. Fong of the Ballistics Branch, Direct Fire Weapons Division and Propulsion Division, Weapons Systems Research Laboratory, Defence Research Centre Salisbury, South Australia, on assignment to DLDL, was the project engineer for this effort.

This report has been reviewed by the Public Affairs (PA) Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARVIN J. WOODRING, Colonel, USAF
Chief, Direct Fire Weapons Division

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SECTION I

INTRODUCTION

The gasification rate, dN/dt, of a burning propellant is defined by:

$$dN/dt = r.\rho_p.s_b$$

where r is the linear burning rate, ρ_p is the density of the propellant, and s_b is the burning surface area of the propellant. Thus the peak chamber pressure and ultimately the piezometric efficiency are dependent upon r and s_b for a particular propellant. Normally r shows an Arrhenius-type dependency upon temperature (r decreases as the temperature decreases) and s_b decreases with time as a function of r. Changes in the structural integrity of the propellant grains will lead to a change in s_b and hence the gasification rate and peak pressure. Grain fracture will cause an increase in s_b and hence increase the gasification rate. Grain softening and deformation such as result in a closing of the perforations will cause a decrease in s_b and thereby decrease the peak pressure.

In a recent report (Reference 1), we presented a systematic study of the temperature sensitivity of a number of single base, double base, triple base, and nitramine propellants in the GAU-8/A 30-mm gun. From plots of V_m^2/P_p* (where V_m is the muzzle velocity and P_p is the peak chamber pressure) versus charge weight (CW) at different temperatures (T), it was possible to clearly identify which propellants exhibited anomalous ballistic behavior and to demarcate the temperature regimes in which such anomalous behavior occurred. Propellants which behaved normally during the ballistic cycle showed a linear relationship between V_m^2/P_p and CW (at varying temperatures) with substantial negative slopes. However, it was observed that the triple base propellants

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*V_m^2/P_p is proportional to the piezometric efficiency for a constant ballistic configuration.

all displayed marked reductions in piezometric efficiency at -10°C and below. Certain batches of the triple base propellants also displayed temperature independent ballistics from -10° to 50°C, and anomalously high and low piezometric efficiencies at 70°C. The single base, double base, and nitramine propellants all showed normal temperature sensitivity over the range from -50° to +70°C, as judged from their V_m^2/P_p versus CW plots.

The anomalous temperature sensitivity of the triple base propellants was considered to be in accord with the postulate that substantial grain shattering was occurring below -10°C in all batches of this type of propellant. In certain batches, however, some smaller and diminishing degree of grain fracture was still occurring as the temperature increased from approximately -10° to approximately 50°C. Such a phenomenon could then account for the observed temperature insensitive ballistics, since a corresponding increase in propellant burning surface (due to grain fracture) as the temperature decreases would effectively counter the well known decrease in inherent burning rate of the propellant as the temperature decreases. The observation that certain batches of triple base propellant can give anomalously high piezometric efficiencies (low P_p) at 70°C is then explicable in terms of grain fracture occurring below 70°C but not at 70°C (i.e., the propellant is behaving normally at 70°C, while increased surface area from grain fracture below 70°C leads to higher P_p than that observed at 70°C). However, other batches of triple base propellant gave unusually low piezometric efficiencies (high P_p) at 70°C, a result which is difficult to rationalize.

The increased propensity towards brittle fracture at sub-ambient temperatures displayed by the triple base propellants is to be expected and is in accord with measures of material strength obtained from laboratory impact tests and closed vessel tests (References 2 through 10). The expectation is based upon increased brittleness of the nitrocellulose-nitroglycerine binder and especially the binder-solid oxidizer (nitroguanidine) interface as the temperature is lowered. However, less is known about anomalous ballistic behavior at higher temperatures. The M30A1-M203 propelling charge is known to suffer from intermittent high temperature ballistic problems (Reference 11).

This report describes the temperature sensitivity of a number of double base ball and rolled ball propellants, extruded double base, triple base, nitramine, and some highly plasticized extruded propellants in the 20-mm, 27-mm, and 30-mm guns. The work draws substantially upon our previous report (Reference 1) as background knowledge and constitutes a portion of our continuing study of the temperature sensitivity of a wide range of small arms propellants. In particular, it is hoped to gain further insights into the relationship between anomalous low and high temperature ballistics and the structural integrity of propellant grains.

SECTION II

EXPERIMENTAL

The 30-mm gun firings were made in a GAU-8 single-shot Mann barrel at Eglin Air Force Base utilizing 428-gram Aerojet 30-mm GAU-8/A projectiles with plastic rotating bands and 30-mm GAU-8/A aluminum cartridge cases. The ignition system was comprised of a M52 primer with WECOM 30 flashtube containing 0.35 gram of Class 4 black powder. An ignition aid of 0.75 gram of boron/potassium nitrate (added as a powder) was used with the triple base propellant.

The 20-mm gun firings were made in an M61 single-shot Mann barrel at Eglin Air Force Base utilizing 98-gram M55 projectiles. The ignition system was an electric M52 primer.

All rounds were temperature conditioned for a minimum of 48 hours and fired as soon as possible (within approximately 60 seconds) after being removed from the environmental chamber.

The data obtained at Eglin Air Force Base were the averages of multiple firings (usually 3 to 5) with the exception of the data in Figures 6, 8, and 14 where the shortage of propellant precluded multiple firings.

The propellant compositions and geometries for 30-mm GAU-8/A application are given in Table 1. The WC870 and WC872 propellant used in the 20-mm gun were supplied from the Olin Corporation as was the WC 895 30-mm propellant.

All propellant was preconditioned at 40°C for one day before loading to minimize the influence of humidity on gun ballistic data. Maximum care was taken to ensure that ballistic conditions for a particular propellant were as similar as possible. Daily calibration of pressure gauges and parallel firings of reference and comparison rounds were carried out to minimize drift of the Kistler pressure gauges.

TABLE 1. COMPOSITION AND GRAIN DIMENSIONS FOR DOUBLE BASE, TRIPLE BASE, NITRAMINE, BUTYLNENA AND BALL PROPELLANTS FOR 30-MM GAU-8/A APPLICATION

PROPELLANT INGREDIENTS	GAU-8 EXTRACT	IH.3	TRIPLE BASE NO. 26	WC895	ButylNENA
NC (12.2 N)			28.6		
NC (12.6 N)	82.3	20.0			8.8
NC (13.2 N)				83.3	
NG	9.4		18.6	8.4	
Plasticizer	4.3	4.8		1.1	9.8
TAGN (4-5 μ)		45.0			
HMX (4-5 μ)		29.5			
RDX (4-5 μ)					65.0
NQ			51.4		
EC			1.4		
BuNENA					15.8
Additives	1.3	0.7	0.8	2.2	
DETERRENT					
EC			1.3		
G-54	3.0	0.3			1.0
DBP				4.9	
Perforations	1	7	7	-	7
Length, in	0.080	0.242	0.147	-	0.124
Diameter, in	0.077	0.212	0.123	-	0.124
Avg Web, in	0.035	0.046	0.021	0.060	0.016

NC	Nitrocellulose
NG	Nitroglycerine
TAGN	Triaminoguanidine Nitrate
HMX	Sym-Tetramethylene Tetranitramine
RDX	Sym-Trimethylene Trinitramine
NQ	Nitroguanidine
EC	Ethyl Centralite
G-54	Rohm and Haas Proprietary Polyester Resin
DBP	Dibutyl Phthalate
ButylNENA	N-n-butyl-N-(2-nitroxyethyl) nitramine

SECTION III

DISCUSSION

We have previously shown (Reference 1) that normal temperature sensitivity of a propellant results in a series of parallel lines (equally spaced when the environmental temperatures are separated by a constant temperature difference) when piezometric efficiency (represented as V_m^2/P_p) is plotted against charge weight. Figure 1 shows such a plot for GAU-8 extract*, an inhibited double base propellant (Table 1). A series of equally spaced parallel lines with negative slopes is observed; such a plot is equivalent to a linear relationship in a three-dimensional plot of V_m^2/P_p versus CW versus temperature. The propellant is inhibited with a polymeric coating (G 54) which effectively removes the possibility that the inhibitor/deterrent may migrate into the propellant matrix upon prolonged storage at high temperature hence affecting ballistic properties (especially piezometric efficiency).

Abnormal propellant temperature sensitivity can result in unusually low or occasionally high piezometric efficiencies at certain temperatures such that a plot similar to Figure 1 does not show a series of parallel lines decreasing regularly (with respect to the V_m^2/P_p axis) with temperature. Such behavior was observed for a number of triple base propellants (Reference 2), especially at low temperatures (-20° to -40°C). We have previously suggested that low piezometric efficiencies at low temperatures is strongly suggestive of propellant grain break-up, i.e., increased propellant burning surface results in an increased P_p or decreased piezometric efficiency.

*GAU-8 extract is the propellant extracted from GAU-8 30-mm TP rounds for in-house evaluation.

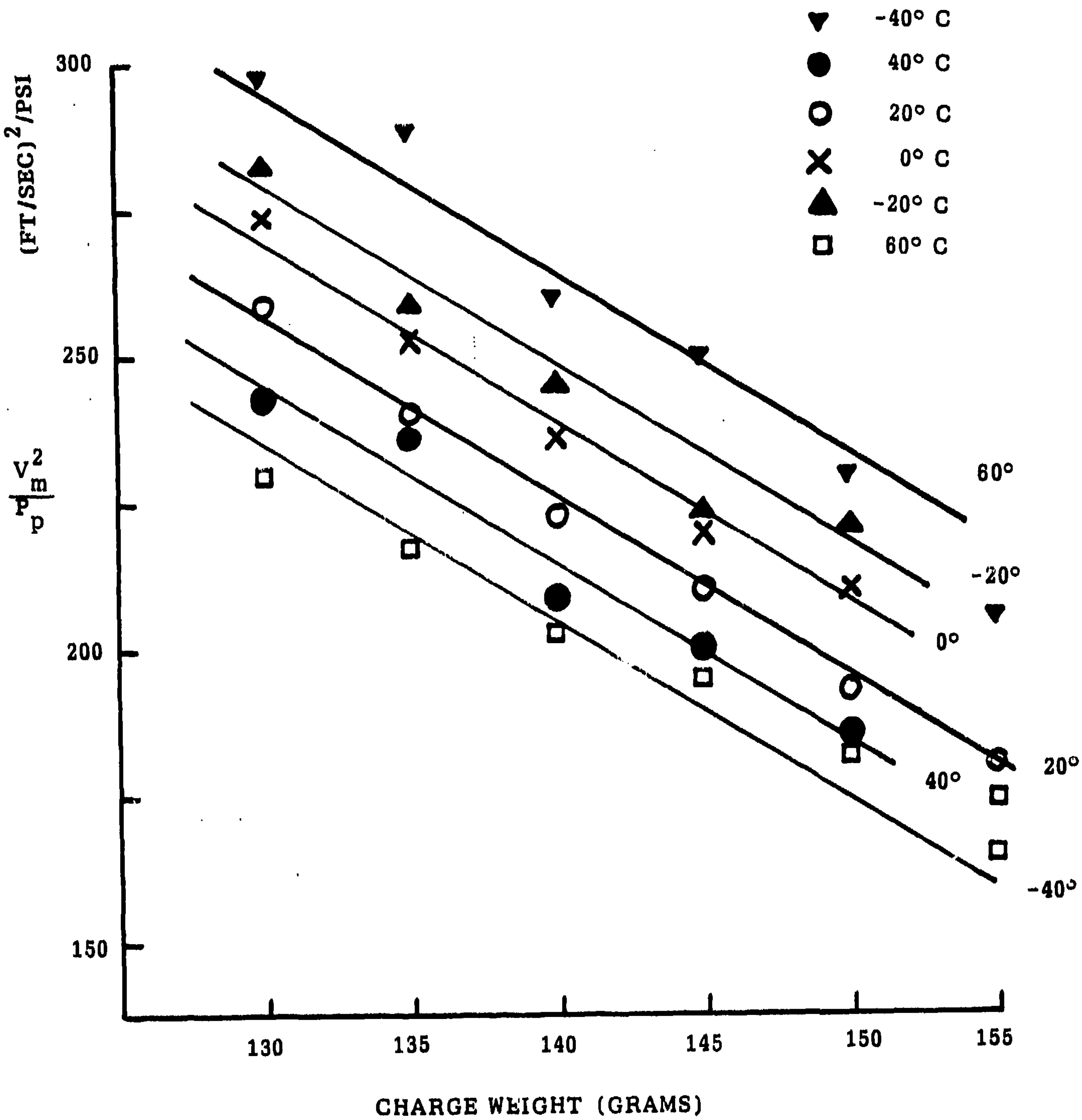

Figure 1. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Propellant GAU-8 Extract

The projected scenario for such a phenomenon originates in an extremely rapid forward compaction of the propellant bed during base ignition such as undoubtedly occurs in 20-mm and 30-mm ammunition. Grain fracture at the leading edge of the propellant bed as the bed strikes the projectile base is known to occur especially at low temperatures when the propensity towards brittle fracture is strongly exacerbated. Ullage between the top of the propellant bed and the projectile base [such as occurs in reduced charge weight (CW) rounds] will increase the velocity at which the propellant grains impact the projectile base under base ignition (Reference 3).

We have not previously seen any evidence for this phenomenon in the 30-mm gun. However, Figure 2 shows the temperature sensitivity of the triple base propellant No. 26. This propellant differs from the six triple base propellants previously examined (Reference 1) in that 12.2 percent N nitrocellulose was used instead of 12.6 percent N nitrocellulose (otherwise, the formulations and grain geometries were very similar).

Figure 2 indicates that the -40°C data displays anomalously low piezometric efficiencies at high CW's (from 140 to 150 grams), suggesting brittle grain fracture is occurring. However, at low charge weights (below 140 grams) the 0°, -20°, and -40°C lines show sharp slope changes indicating the piezometric efficiencies are markedly reduced, especially for -20° and -40°C. The action times (AT) for all data at 0°, -20°, and -40°C did not show any evidence for unduly long ignition delays at any CW's. These data appear to be strong evidence in support of the proposition that ullage above the bed allows higher impact velocity of grains against the projectile base to occur under base ignition. It is also noteworthy that the 60°C data indicate the piezometric efficiencies are somewhat higher than expected (i.e., the P_p's are lower) from a consideration of the 0°, 20°, and 40°C data. However, we will defer discussion of high temperature effects until later in the text.

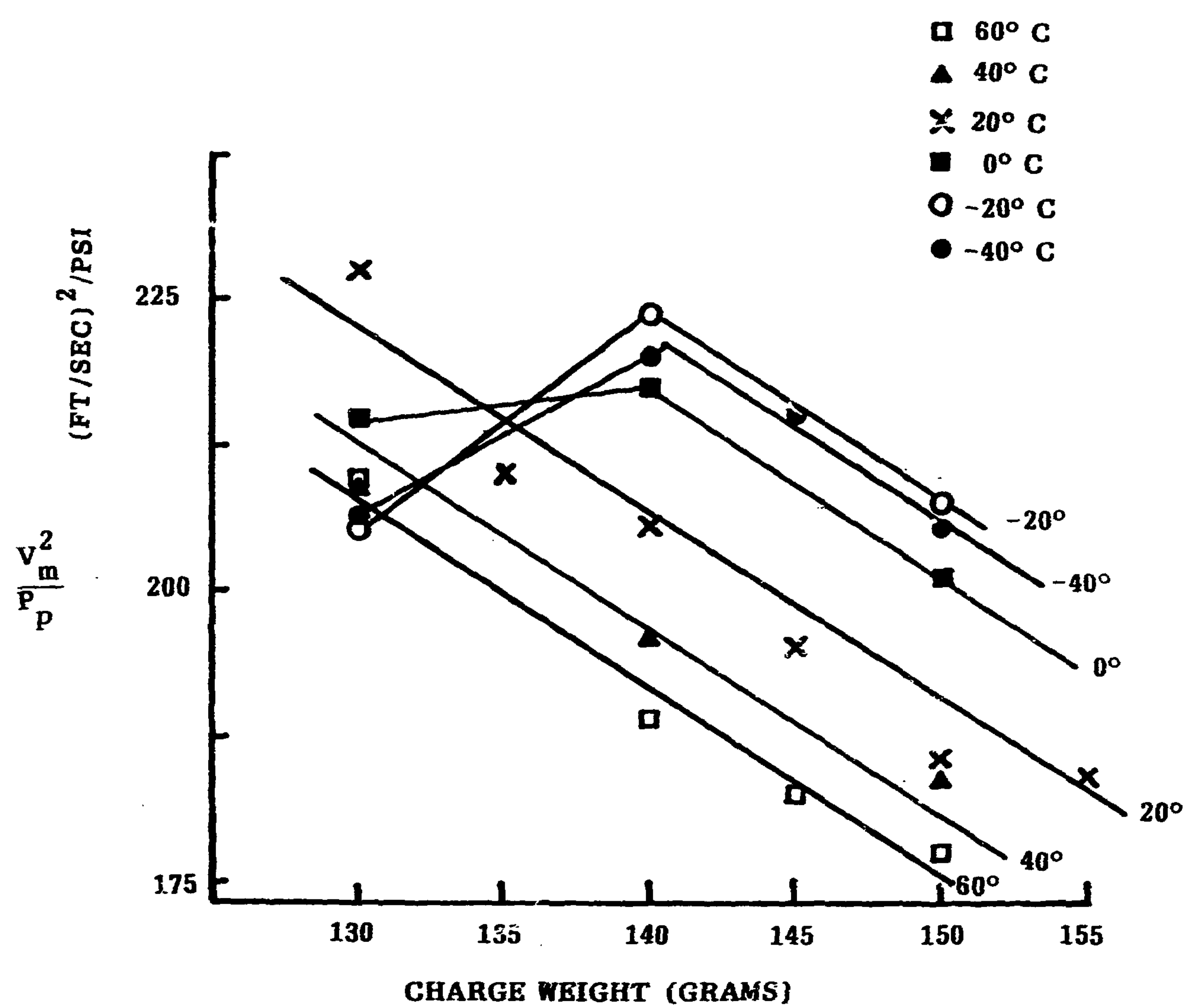

Figure 2. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Triple Base Propellant Number 26

It appears then that using 12.2 percent N nitrocellulose instead of 12.6 percent N nitrocellulose in the triple base formulation makes the propellant matrix more susceptible to low temperature brittle fracture especially at reduced CW's, but not necessarily so at full CW's (Reference 12). If this effect is real, it suggests that the triple base propellant matrix containing 12.2 percent N nitrocellulose displays different strain rate dependent brittle fracture behavior than the analogous propellant containing 12.6 percent N nitrocellulose. There is some support in the literature for the notion that 12.2 percent N nitrocellulose can be more brittle than 12.6 percent N nitrocellulose (Reference 13).

To emphasize that the behavior shown by triple base propellant No. 26 at low CW is not unique, the temperature sensitivity of the nitramine propellant, IH.3, has been investigated at -55° and -70° C, extending the temperature range of the previously reported data for IH.3 (Reference 1). In Figure 3 it can be seen that at -55° C, the piezometric efficiencies at CW's below 135 grams are lower than those at CW's above 135 grams. However, at -70° C, the slopes of the best fit lines are not parallel to those of the other temperatures even at high CW's. Thus, the difference between the -55° and -70° C data are both consistent with the reduced CW hypothesis and the expectation the propellant will become more brittle at lower temperatures. So at high CW's, at -70° C the propellant is so brittle that even with little ullage above the bed, grain fracture can still occur and gets progressively worse at lower CW's. At -55° C, IH.3 appears to retain its structural integrity at full CW's, but at reduced CW's grain fracture can occur. The AT's indicated little evidence of unduly long ignition delays at -55° and -70° C.

The temperature sensitivity of small arms ball propellant has been known for some time to produce anomalous results (References 14 through 16). Pressures

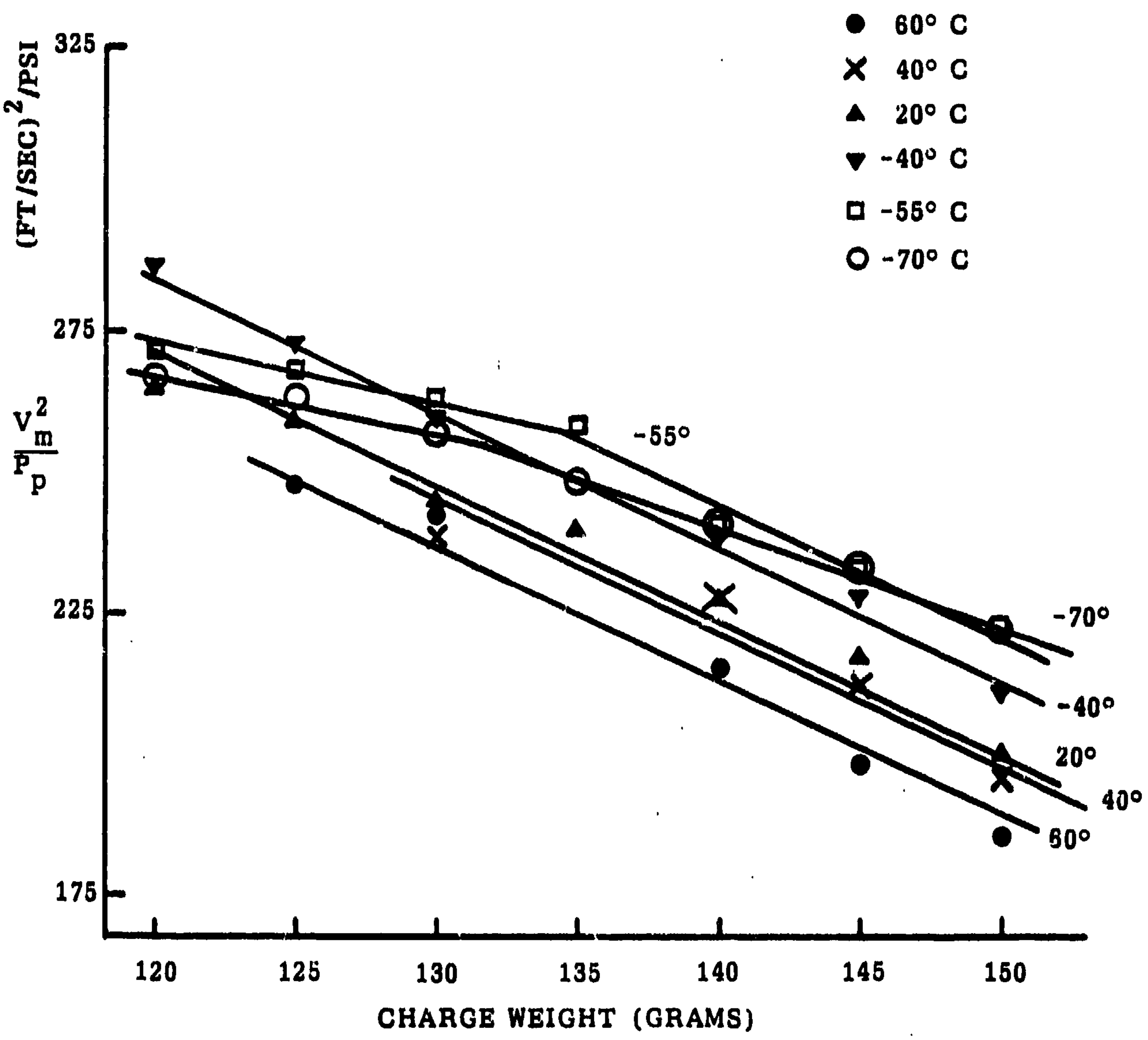

Figure 3. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Nitramine Propellant JH.3

at low temperatures have been known to be either less, equal to, or greater than those obtained at high temperatures. However, rolled ball propellant has been shown to exhibit a much smaller temperature coefficient of pressure between low and ambient temperature than did the unrolled ball propellant. It has also been observed that rolled ball propellant in the 30-mm T239 round gave lower pressures and velocities at 165°F than those obtained at 70°F, whereas the unrolled propellant exhibited normal behavior (Reference 15).

Ashley has shown that the susceptibility of ball propellant to grain fracture by primer blast is dependent upon the degree of distortion induced by rolling (Reference 16). The rolling of ball propellant produces distortions in the grain resulting in the formation of small cracks. We have previously noted that some triple base propellants which showed extensive grain fracture below approximately -20°C also displayed regions from approximately -20° to 50°C in which temperature independent ballistics were observed (Reference 1). It was postulated that the temperature independent ballistics were explicable in terms of a small and diminishing amount of grain fracture occurring as the temperature increased from -20° to 50°C. Such a mechanism would effectively counter the well known decrease in inherent burning rate of the propellant as the temperature decreased, thereby resulting in an apparent temperature independent ballistic sensitivity. It may well be that rolled ball propellant may exhibit a similar degree of temperature insensitive ballistics, particularly in comparison to the unrolled ball propellant.

Figure 4 shows a plot of V_m^2/P_p versus CW for the double base ball propellant WC870 in the 20-mm gun. It can be seen that at -5°, -30°, and -55°C that anomalously low piezometric efficiencies are observed, strongly suggesting that brittle grain fracture is starting to occur at -5° and becomes progressively worse at -30° and -55°C, respectively. At 20°, 50°, and 70°C, the pro-

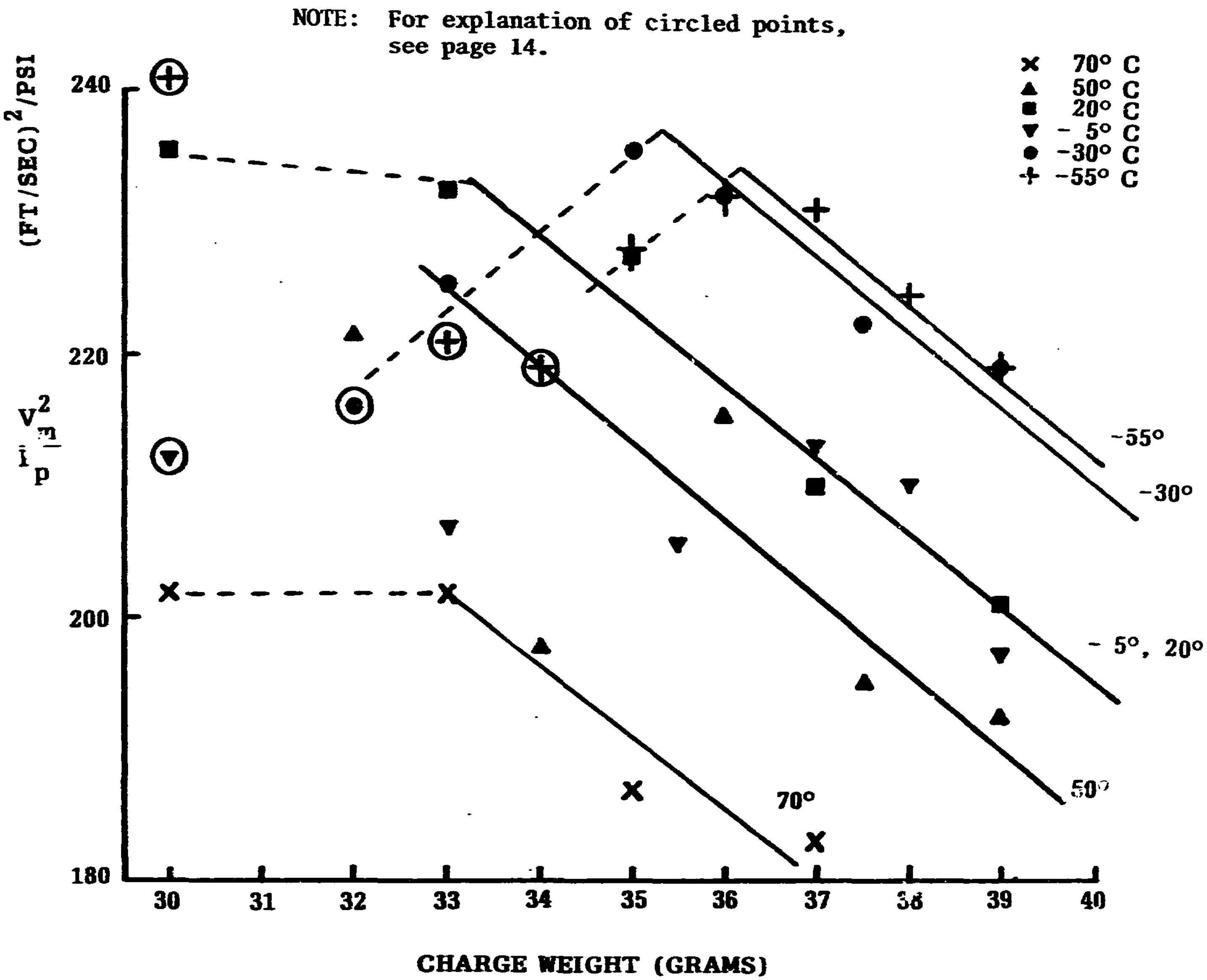

Figure 4. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC870

pellant appears to be behaving normally. The other notable feature of Figure 4 is the large decreases in piezometric efficiency at low charge weights (less than 90 percent of a full CW) at all temperatures. The circled points exhibited long AT's, indicating severe ignition problems if the CW is less than 90 percent of the maximum CW. Such behavior has been repeatedly noticed earlier (Reference 17) and appears to be a feature of all ball propellants.

It is important to point out the difference between the anomalously low piezometric efficiencies observed at low charge weights for ball propellant and that occurring in the triple base and nitramine propellants (Figures 2 and 3). In the former case, the low piezometric efficiencies are associated with ignition problems and can occur at all temperatures. When low CW's lead to low piezometric efficiencies in the triple base and nitramine propellants, the problem only occurs at low temperature and can be attributed to brittle grain fracture. There were no indications that ignition problems were occurring.

Stiefel (Reference 11) has previously noted that WC870 in the 20-mm gun showed P_p's of 295, 342, and 448 MPa at -54°, 21°, and 71°C, respectively. It was thought that the increase of 106 MPa in P_p in going from 21° to 71°C was anomalous and possibly due to ignition and flame spread problems at high temperature. The data in Figure 4 suggests the reverse: The low temperature data is anomalous, producing high P_p's due to grain fracture; the high temperature data appears normal.

Figures 5 and 6 display the temperature sensitivity data for two batches of propellant WC870 (Stock and Olin) at high CW's (greater than 90 percent of full CW) in the 20-mm gun. Both figures show essentially the same features as Figure 4 at high CW's: (a) brittle fracture producing anomalously low piezometric efficiencies at -5°C and below, (b) relatively normal temperature sensitivity at 20°, 50°, and 70°C, and (c) batch WC870 (Olin) shows significantly

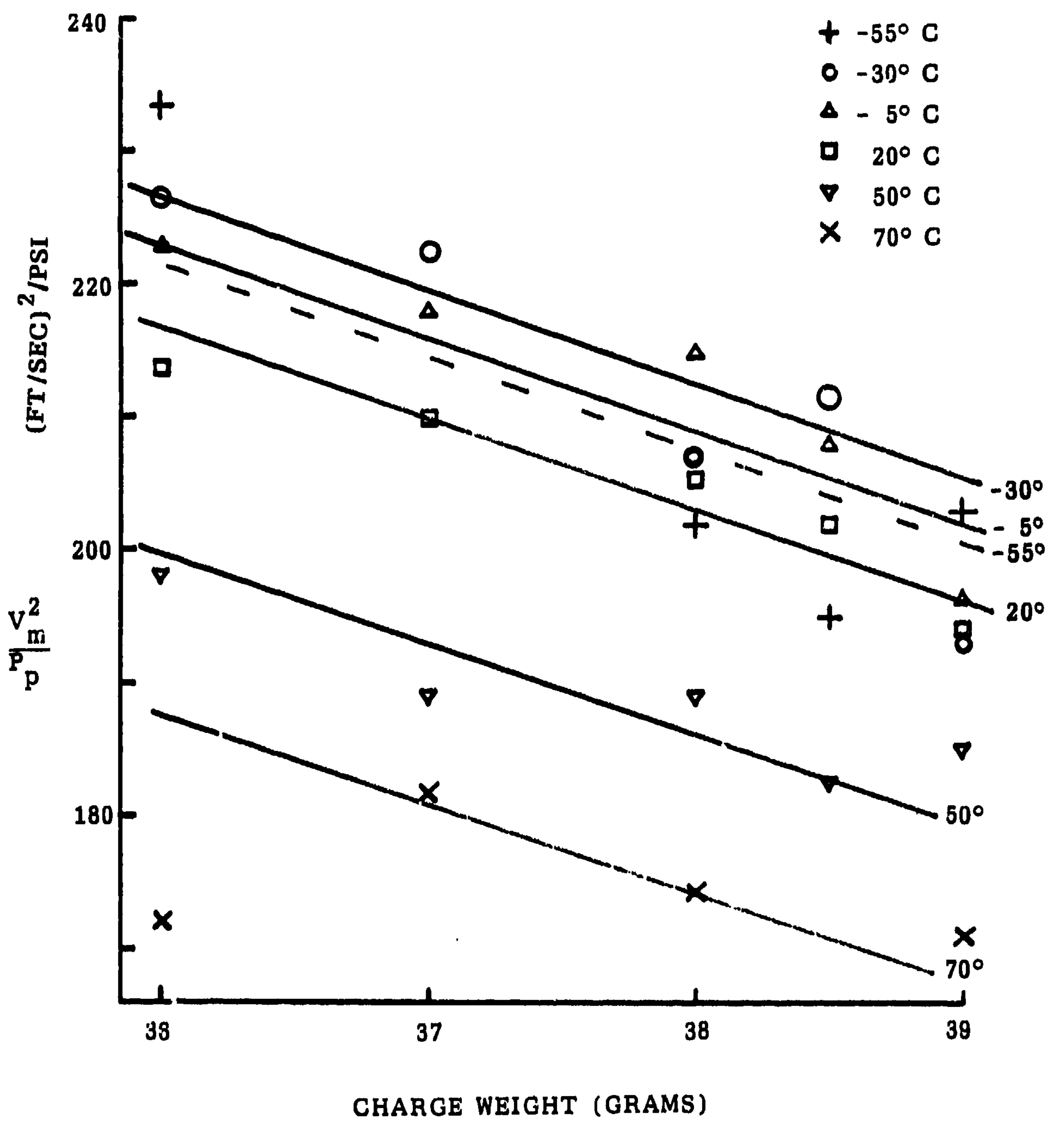

Figure 5. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC870 (Stock)

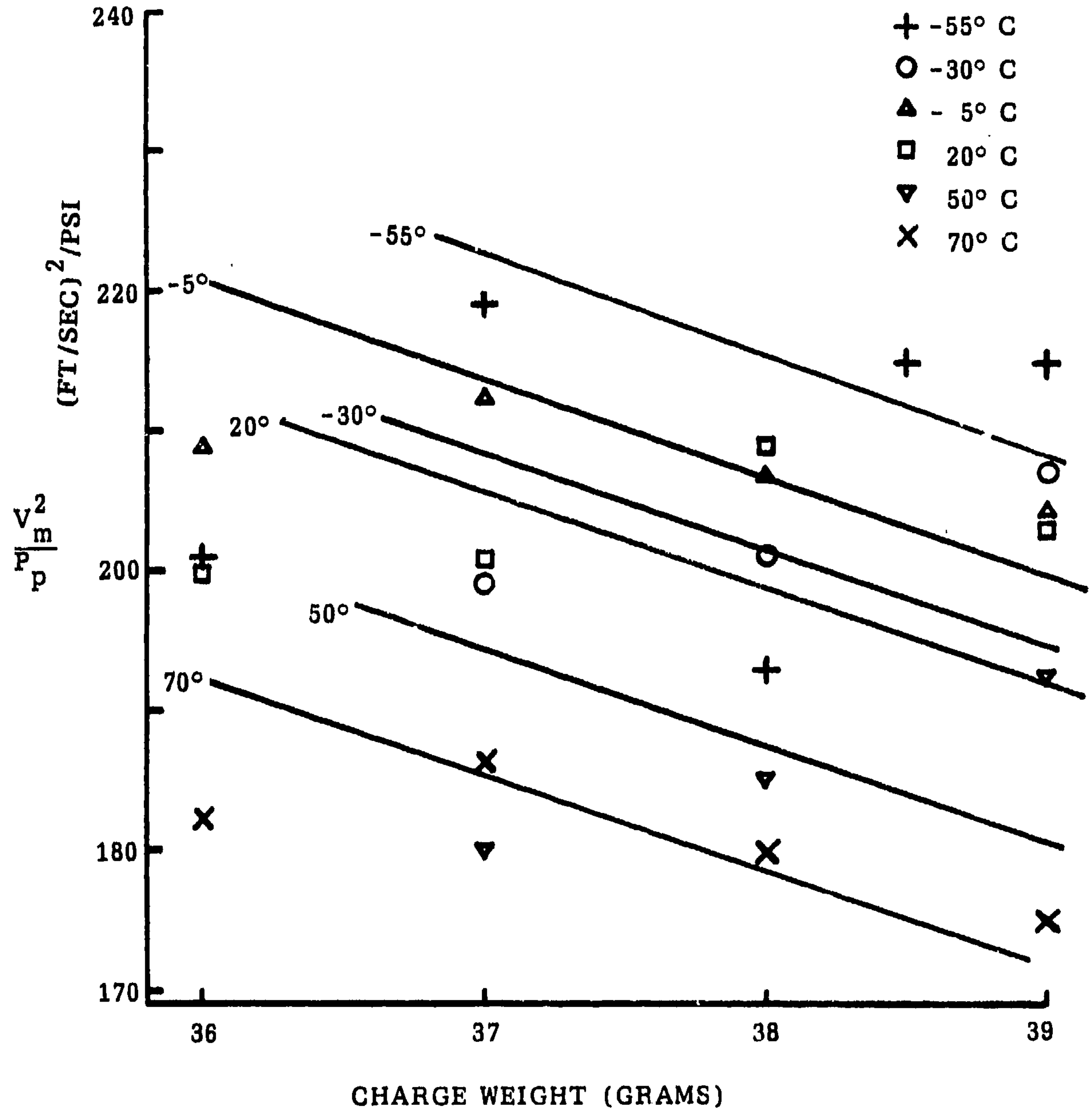

Figure 6. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC870 (Olin)

higher piezometric efficiencies than the Stock batch at 70°C. The latter result may represent a difference in propellant material properties between the two batches at 70°C.

Figures 7 and 8 show the temperature sensitivity data for two batches of the rolled ball propellant WC872 (batches: Stock and Olin) in the 20MM gun. Essentially, WC872 has the same formulation as WC870 but is a rolled ball propellant instead of the spherical grains of WC870. Both Figures 7 and 8 show the same overall pattern, but the Stock batch is much faster (gives lower overall piezometric efficiencies for all temperatures). Both batches of WC872 display abnormal low temperature sensitivity (below -5°C) which can be attributed to brittle grain fracture processes. However, both batches also show abnormal high temperature ballistics, the 20°, 50°, and 70°C data being roughly equivalent in Figures 7 and 8. The experimental error is rather larger than normal in Figure 8 owing to a limited amount of propellant precluding multiple shots for each data point. But the overall pattern which emerges is that the ballistics of both batches of WC872 show a much greater degree of temperature insensitivity over the range from -55° to 70°C than does the analogous WC870 propellant.

The higher than expected piezometric efficiencies for WC872 at 50° and 70°C can be attributed to a greater degree of retention of grain structural integrity as the temperature increases from -55°C; i.e., at low temperatures the small cracks and stress points induced during the rolling procedure can more easily lead to grain fracture when the propellant matrix is brittle. However, as the temperature increases, the increased plasticity of the propellant material gradually decreases the likelihood of crack propagation leading to grain failure. The situation is analogous to that observed for some triple base batches observed earlier (Reference 1). Stiefel (Reference 14) also

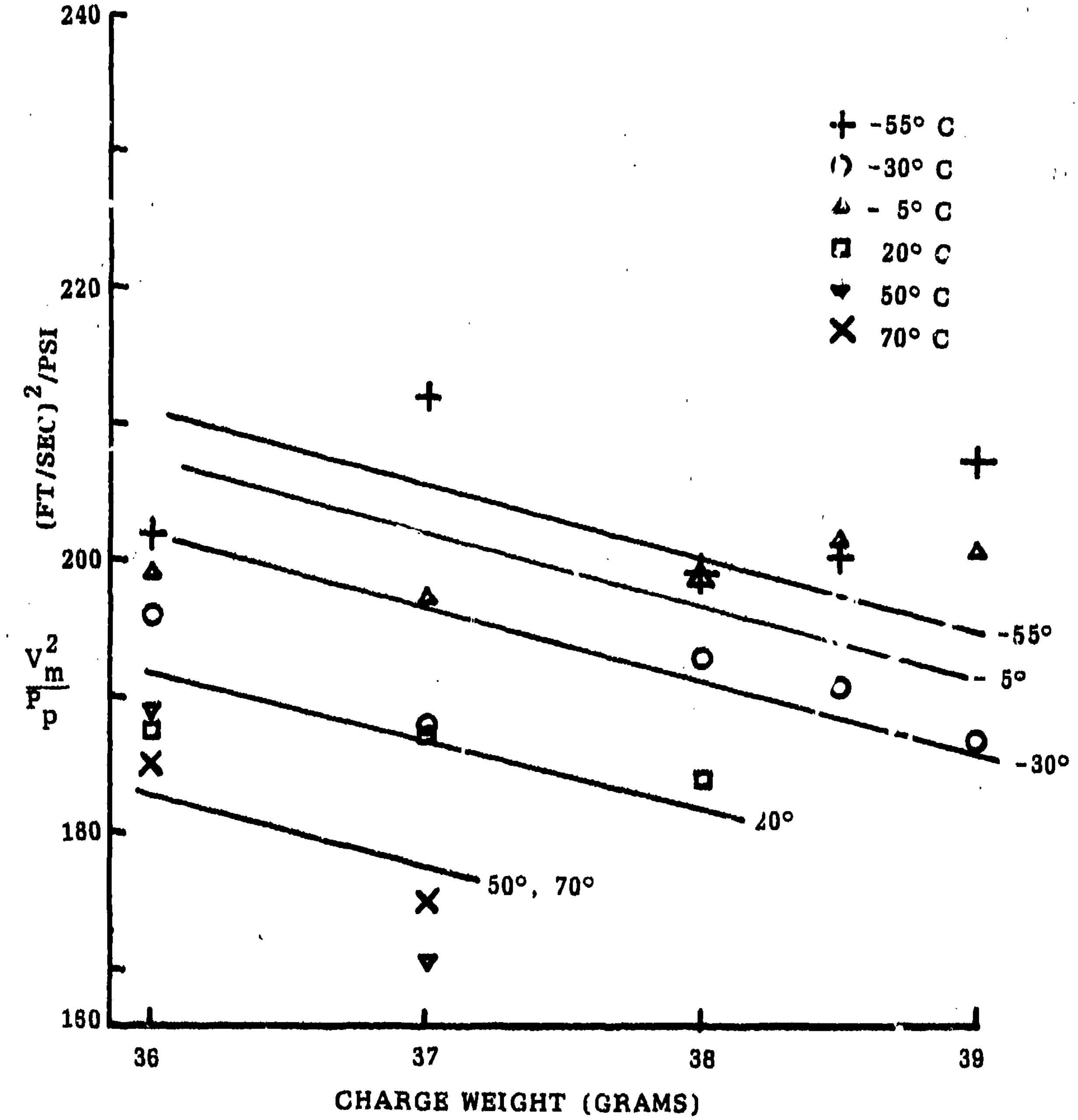

Figure 7. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC872 (Stock)

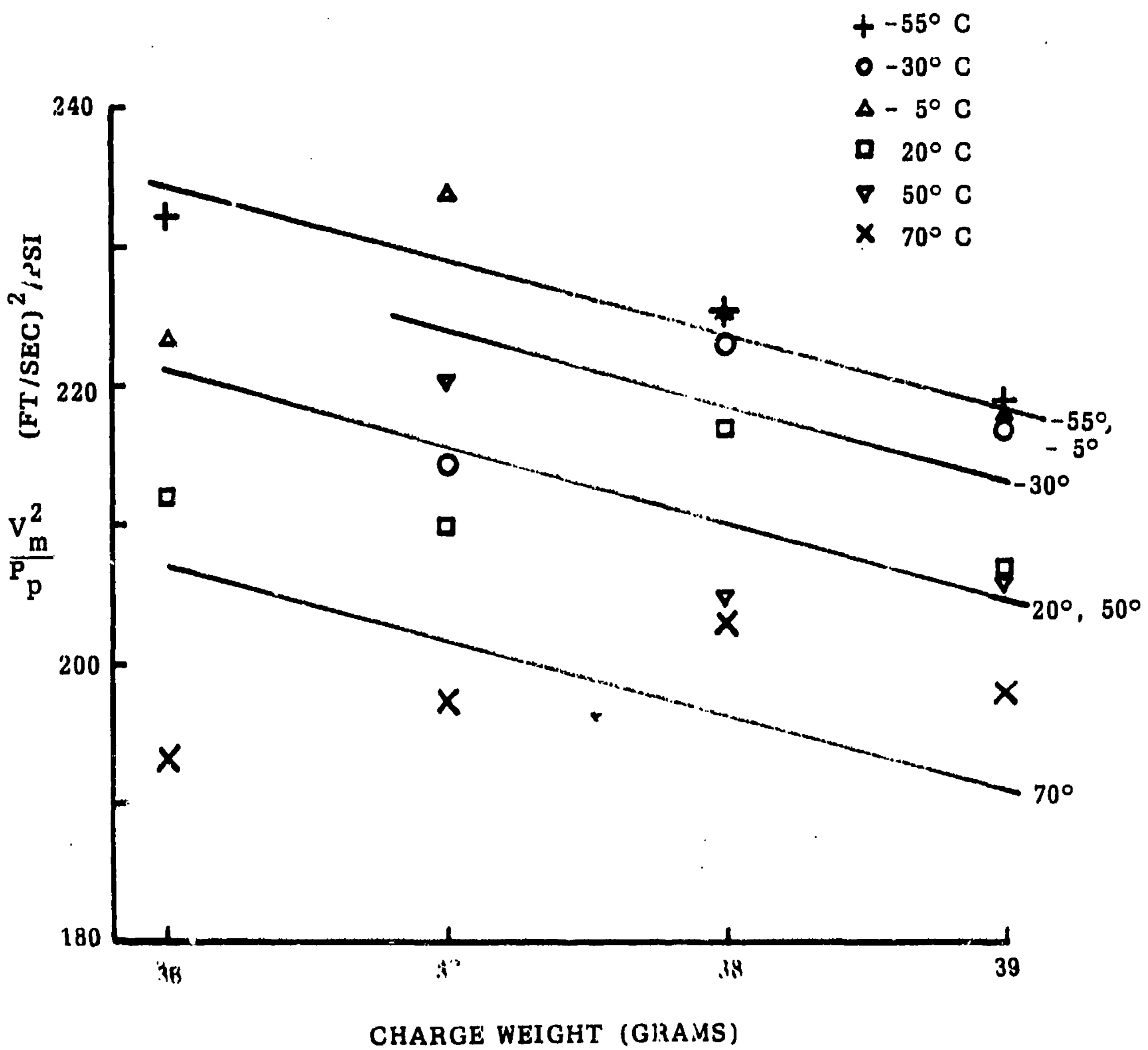

Figure 8. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC872 (Olin)

noted a similar temperature insensitivity of a rolled ball propellant in the 20MM gun (for three temperatures: -54°, 21°, and 71°C, the P_p's observed were 391, 373, and 323 MPa, respectively) as did Levy and Kirshner (Reference 15) in the 30MM gun. The ballistic data in Figures 7 and 8, as well as References 14 and 15, is consistent with Ashley's studies of the degree of grain fracture in rolled ball propellant under ignition impact conditions (Reference 16).

Figure 9 shows the temperature sensitivity data for the rolled double base ball propellant WC895 in the GAU-8/A 30-mm gun. The propellant has recently been qualified for service use in this gun. The data indicated detectable grain break-up below -5° C, though the low temperature break-up does not appear as severe as for the WC870 and WC872 propellants. At high temperatures (70°C), the piezometric efficiencies are higher than expected. Generally, the same pattern of temperature sensitivity is seen for WC895 as for WC870 and WC872 in the 20-mm gun. However, WC895 appears to behave as if its mechanical integrity is less perturbed over the temperature range than the 20-mm propellant. It may well be the ballistic environment in the 20-mm round is harsher (from a point of view of severity of ignition pressure waves) than the 30-mm round, or conversely, the larger grains of WC895 have significantly improved impact strength. The postulate of increased plasticity at higher temperatures reducing propensity toward fracture (previously advanced for WC870 and WC872 propellant) obviously applies to WC895 propellant also.

It has been previously noted (Reference 18) that this propellant showed no change in P_p at 70°F over the charge weight range of 152 to 156 grams. Also the P_p's at 160° and -65°F did not change in proportion to the change in CW. These anomalous results are consistent with the data shown in Figure 9.

It was noted earlier that the triple base propellant No. 26 (Figure 2) also showed somewhat higher piezometric efficiencies than expected at 60°C. A

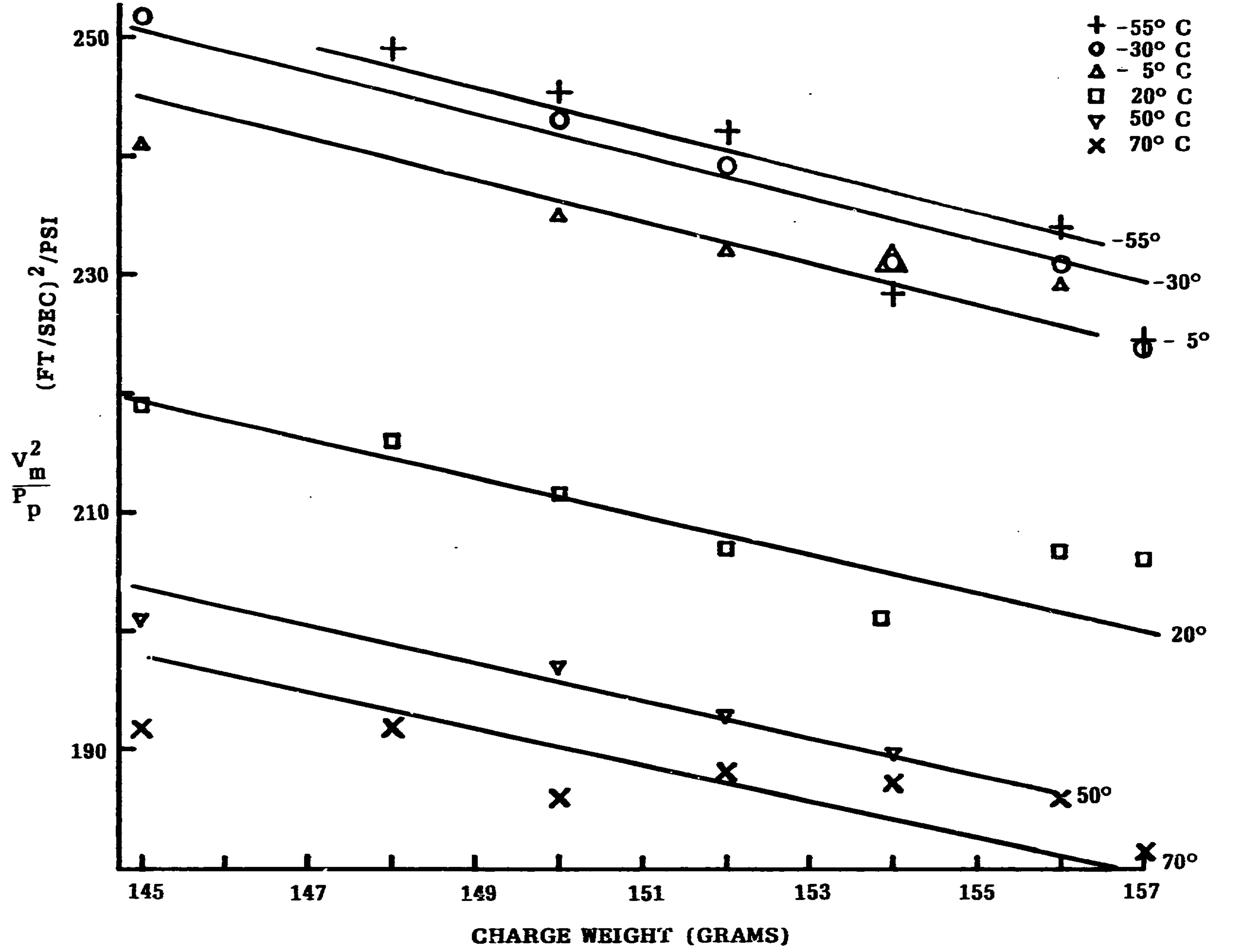

Figure 9. (Muzzle Velocity)^2/Peak Pressure Versus Charge Weight for the Double Base Ball Propellant WC895 (30 mm)

similar explanation as that applied to the rolled ball propellants at high temperature suffices to explain this anomaly. Other batches of triple base propellant containing 12.6 percent N nitrocellulose (instead of the 12.2 percent N nitrocellulose in batch 26) have also displayed unusually low piezometric efficiencies at 60°to 70°C (Reference 19).

It has been argued above that the observation of even lower than expected piezometric efficiencies at high temperature may actually reflect a situation in which a small amount of grain break-up may be occurring at ambient temperatures and above. But at high enough temperatures, the increased plasticity of the propellant can now resist grain fracture so the propellant now behaves in a normal fashion while maintaining its structural integrity. However, while this argument may explain anomalously high piezometric efficiencies at high temperatures, it has often been observed in various propellants that low piezometric efficiencies (or high P_p's) can also occur at high temperature (References 11, 20, and 21). It appears then as if alternate mechanisms may occur to produce such anomalies. Possibilities which could be invoked include chemical effects (such as migration of deterrents, loss of volatile components) or physical effects (such as grain softening and closure of perforations).

Chemical effects can be expected to increasingly dominate upon long term, high temperature storage, but should be relatively unimportant during short term preconditioning at moderately high temperatures (approximately 60° to 70°C). Physical effects, especially grain softening, will be an immediate problem even in short term preconditioning. Thus the high temperature ballistic behavior of propellants which are known to become physically soft at elevated temperatures (especially those containing high properties of plasticizers) may be useful in elucidating the mechanisms which cause low piezometric efficiencies at high temperature.

Hewkin (Reference 22) has previously reported the temperature sensitivity of a nitrocellulose (NC)/diethyleneglycol dinitrate (DEGN) propellant (containing over 20 percent diethyleneglycol dinitrate) in a 27-mm aircraft cannon. The same propellant was also fired in the 0.50 caliber Browning gun at similar P_p's but using a milder ignition system (Figures 10 and 11). The propellant material is physically soft as expected for such a high plasticizer content and is configured as a 19-perforation grain.

The ballistic temperature sensitivity data for the NC/DEGN propellant in the 27-mm gun has been recalculated as piezometric efficiency versus temperature (Figure 12). The marked nonlinearity of this plot is striking. At -40°C, the piezometric efficiency is lower than expected, presumably due to brittle failure of grains. However at high temperatures, from 50° to 70°C, the efficiencies are anomalously lower than expected, yet become higher than expected at approximately 90°C.

The same propellant in the 0.50 caliber Browning gun with a milder ignition system shows an expected linear relationship for normal behaving propellant (Figure 13). Hewkin also notes that if this propellant is fired in the 27-mm gun at lower CW, the velocities and pressure increase smoothly over the whole temperature range.

The data in Figures 12 and 13 strongly imply that, owing to the physically soft nature of the propellant, at full CW in the 27-mm gun, the high temperature ballistic behavior results from severe compression of the propellant bed under primer blast. Partial closure of perforations and distortion of the grains can give both low (50° to 70°C) and high (approximately 90°C) piezometric efficiencies. The behavior of the propellant bed at high temperatures may well be akin to that of a consolidated charge. Obviously a complex interplay of grain deformation and partial closure of perforations and reduced permeability of the compacted propellant bed can result in unusual ballistics.

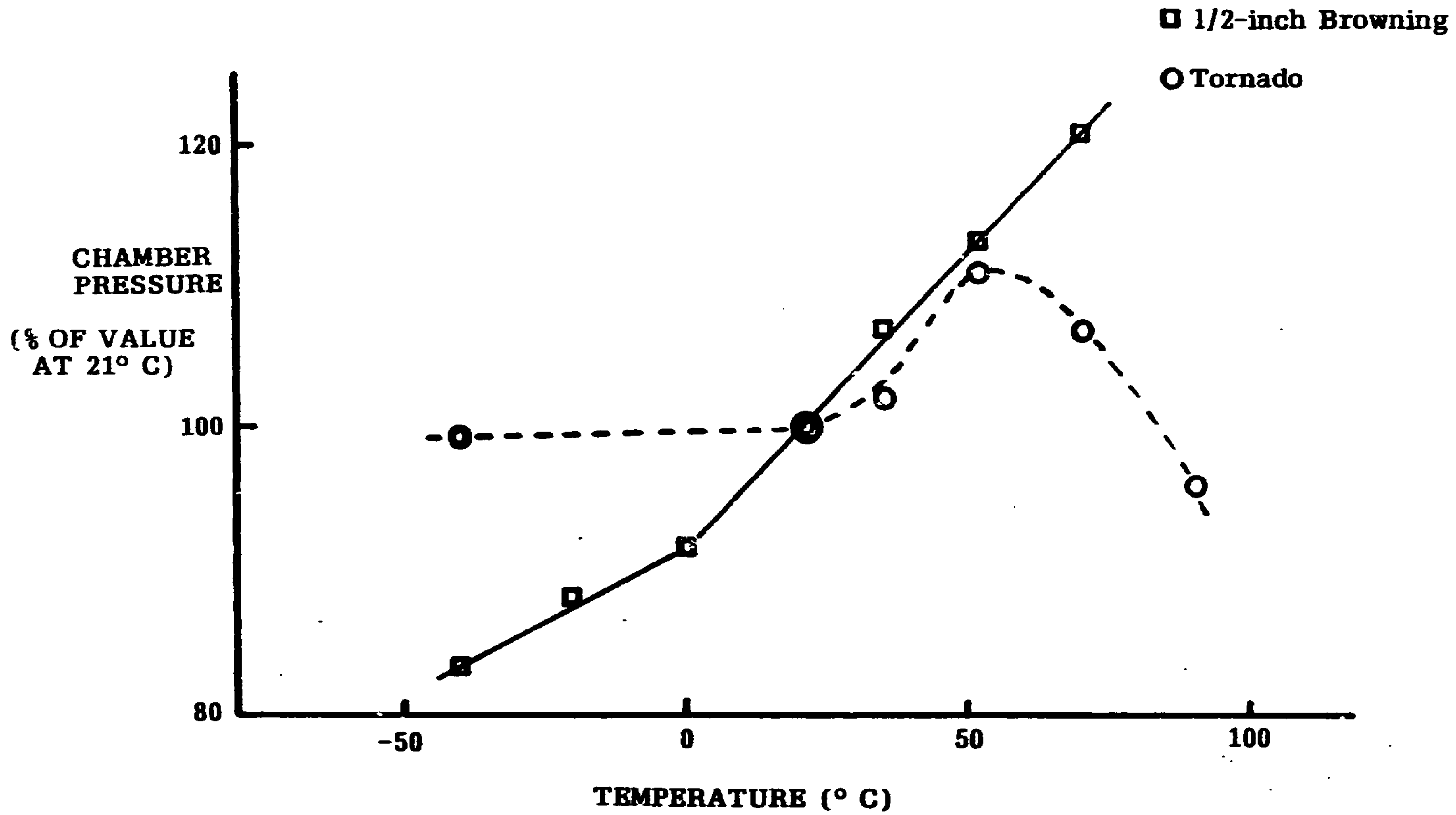

Figure 10. Chamber Pressure Versus Temperature for NC/DEGN Propellant (Hewkin)

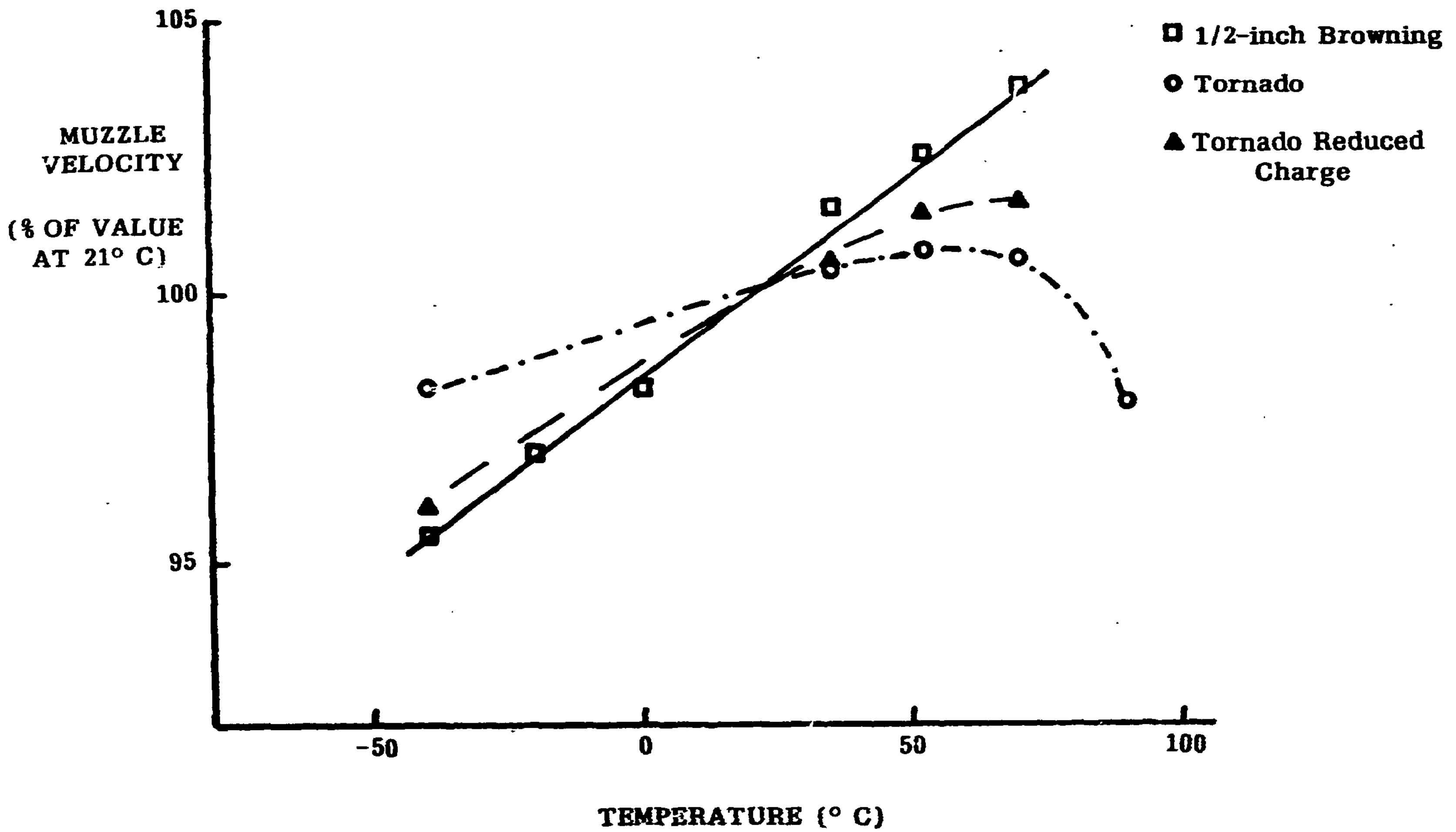

Figure 11. Muzzle Velocity Versus Temperature for NC/DEGN Propellant (Hewkin)

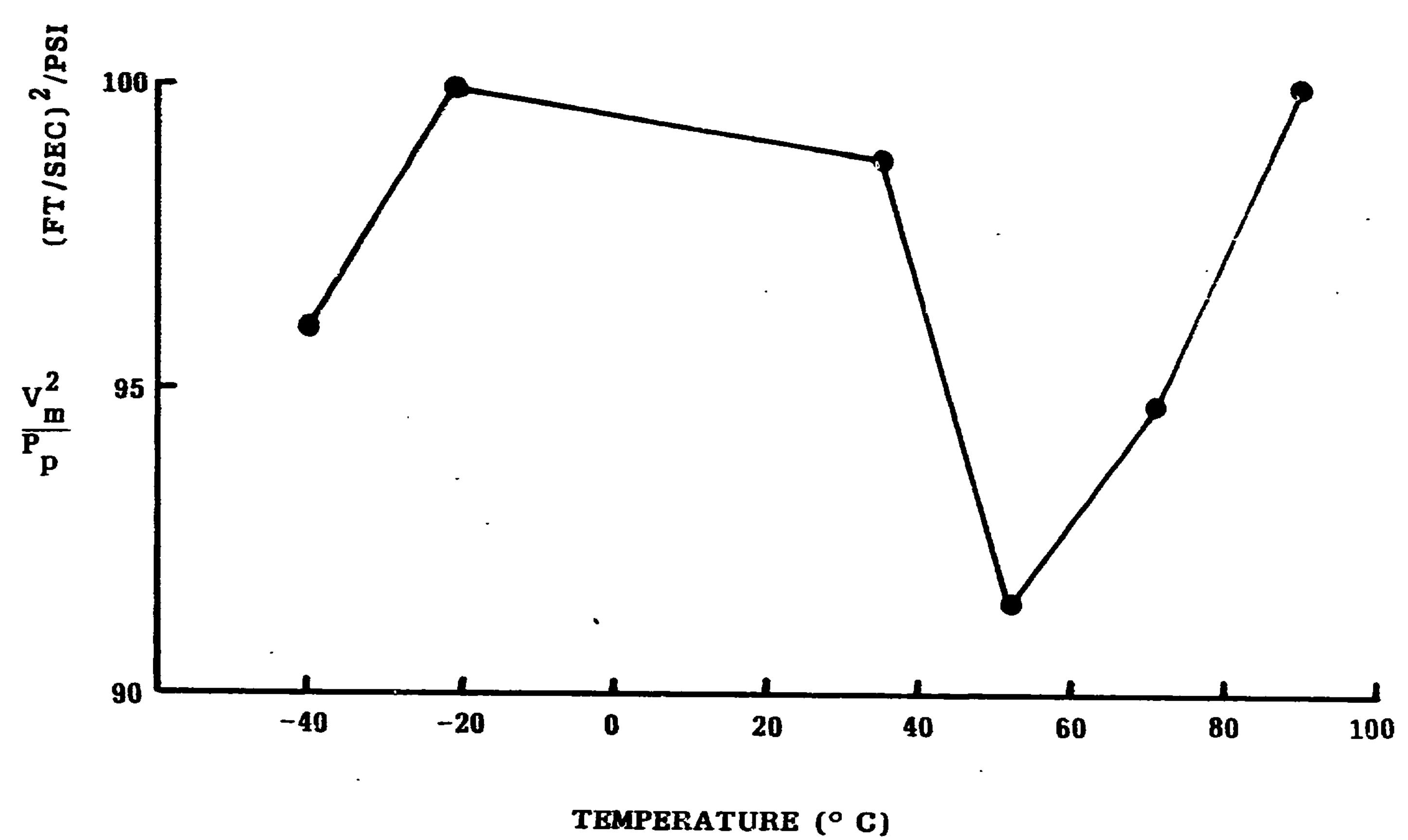

Figure 12. (Muzzle Velocity)^2/Peak Pressure Versus Temperature for NC/DEGN Propellant in the Tornado 27-mm Gun

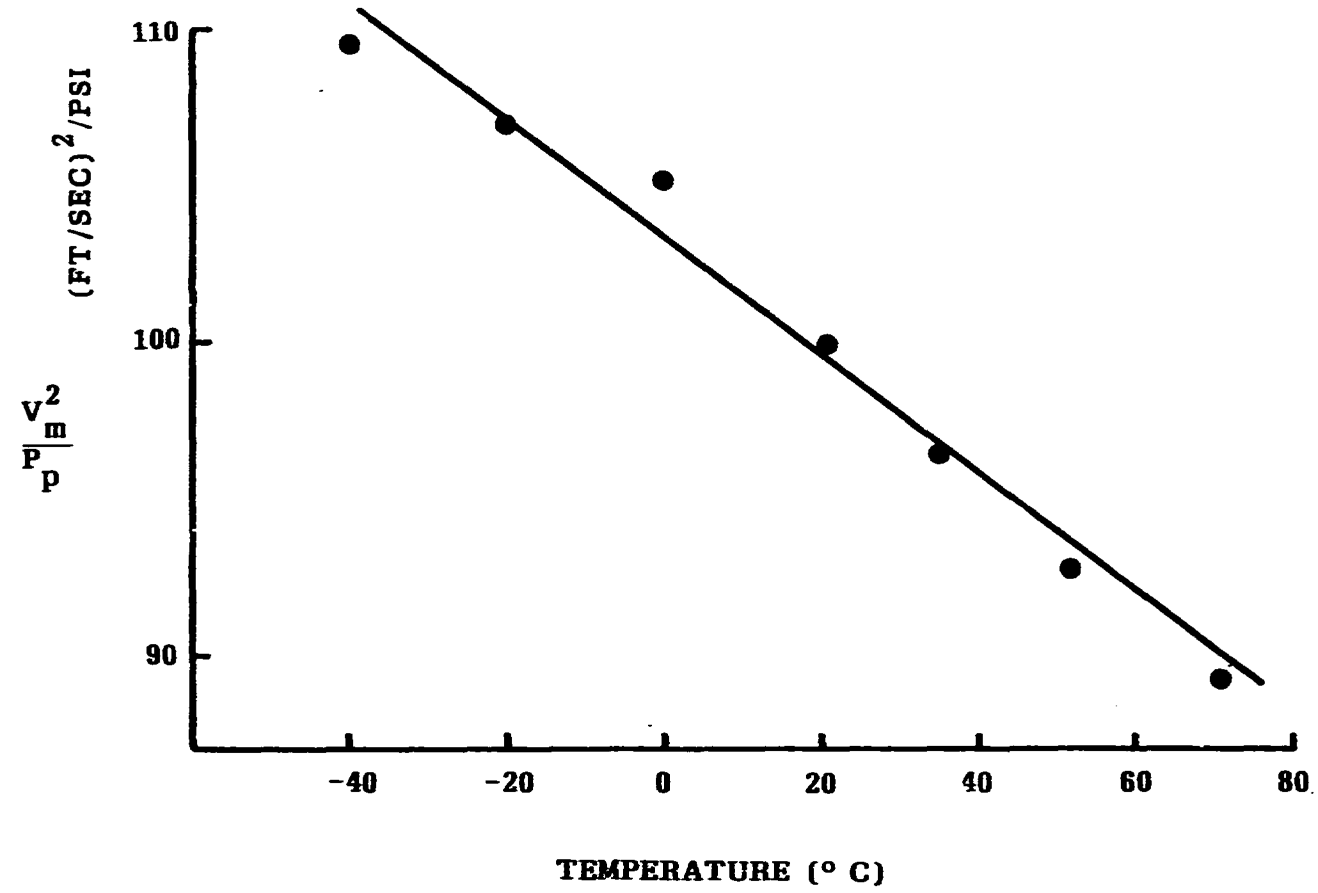

Figure 13. (Muzzle Velocity)^2/Peak Pressure Versus Temperature for NC/DEGN Propellant in the Browning 0.5-inch Gun

Figure 14 shows a plot of P_p versus CW at various temperatures for ButylNENA (BuNENA) propellant. Owing to instrumental difficulties, muzzle velocities could not be obtakned for all the temperature conditioned rounds, hence P_p is used instead of V_m^2/P_p. We have previously noted (Reference 1) that plots of V_m^2/P_p or P_p alone versus T (or CW) generally show the same (though inverse) trends with respect to temperature sensitivity. The BuNENA propellant is physically a soft propellant which can be easily deformed by hand pressure at room temperature (approximately 30°C).

Generally, plots of P_p versus CW for a particular temperature are linear with the exception of the data for 135 grams. At 135 grams, the standard GAU-8/A aluminum cartridge case is slightly overfull, so that projectile insertion results in a small amount of compression of the propellant bed. The data in Figure 14 then indicates this condition results in lower P_p's than would be expected from the P_p versus CW relationship for a particular temperature possibly indicating ignition difficulties. More importantly however, the data at high temperatures indicates that the BuNENA propellant can give unusually high P_p's (at 45° C) or unusually low P_p's (at 70° C).

In fact, at 70° C the average P_p (for triplicate shots) for CW's of 123, 126, 129, 132, and 135 grams were 21.9, 22.6, 20.1, 26.5 and 24.0 KPSI respectively; these multiple shots at each CW were also highly scattered about the average P_p's. It can be seen from Figure 14 that these P_p's are anomalously low. These unusually low P_p's at 70° C can be attributed to incomplete burning of the grains since unburnt grains were found in front of the gun and in the gun.

In contrast to the 70° C data, the data at 45° C exhibits unusually high P_p's. There was little evidence of unburnt propellant at this temperature. The P_p's at the various CW's at 45° C are very similar to those found at -55° C.

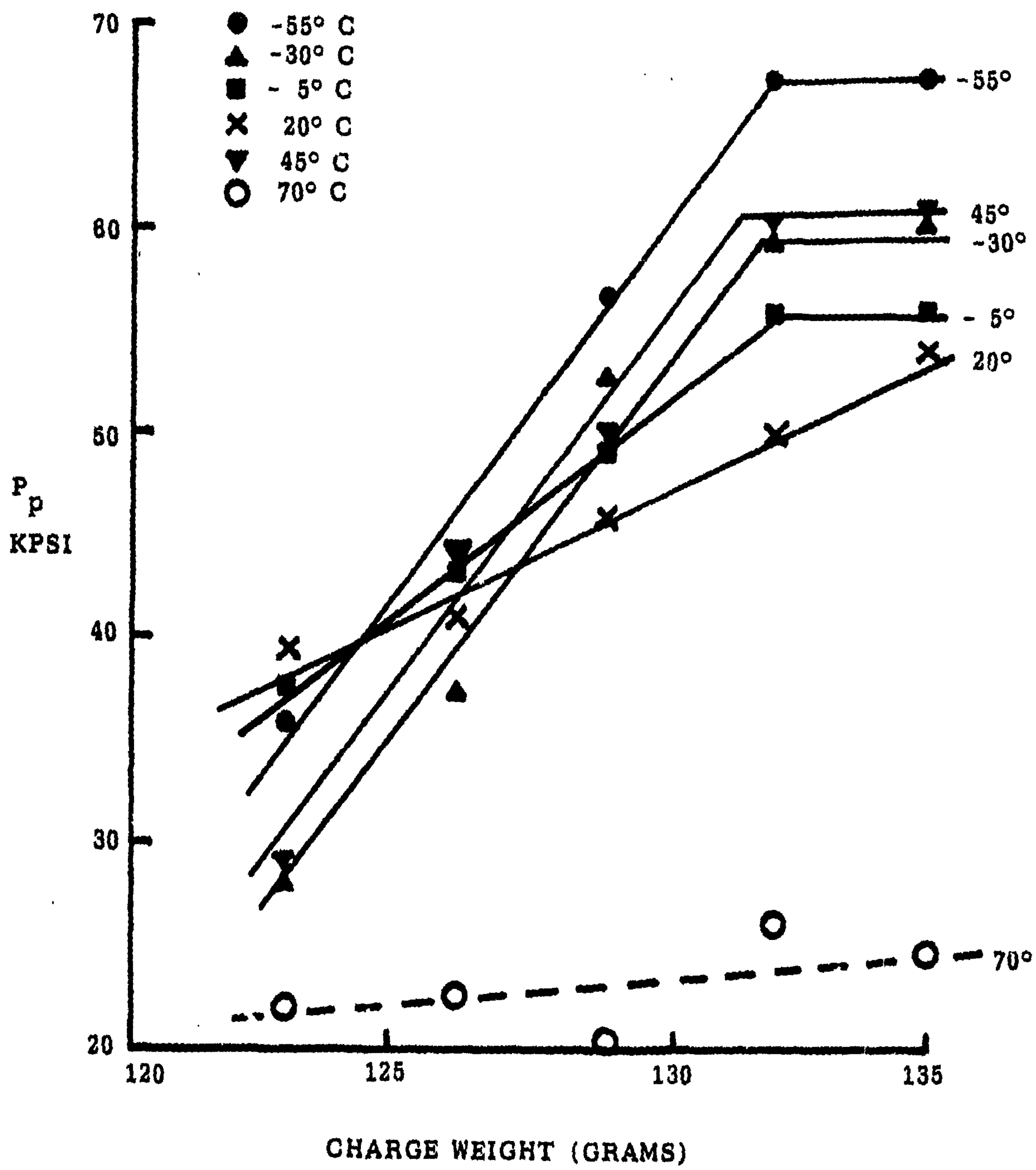

Figure 14. Peak Chamber Pressure Versus Charge Weight for ButylNENA Propellant

However, at moderately high and higher temperatures, the propellant is very prone to plastic deformation under stress. It can be surmised that grain deformation and partial closure of perforations have occurred under primer blast at moderately high temperatures (45°C), but increased softening of the propellant at higher temperatures (70°C) also causes severe compaction of the propellant bed leading to ignition difficulties as well. The pressure versus time traces at 45° and 70°C indicate the presence of significant pressure waves in the gun chamber. Such pressure waves appear to be more severe than previously noted for other propellants fired in the GAU-8/A gun (Reference 1).

The temperature sensitivity of the BuNENA propellant is very similar to that displayed by the NC/DEGN propellant for the 27-mm Tornado gun. The same pattern of high P_p's at moderately high temperatures is found, as well as unusually low P_p's, at higher temperatures (Figure 15). It appears as if this behavior may be common to highly plasticized propellants which are also physically soft at high temperatures. The BuNENA propellant also appears to retain its structural integrity at -55°C far better than the NC/DEGN propellant (compare Figures 12 and 15) at a similar temperature.

These results for the highly plasticized Tornado and BuNENA propellants have serious implications for current USAF programs to incorporate nitramine plasticizers or nitramine polymers into propellants that do not require high solids loadings to achieve the desired goals of low flame temperature and high impetus. The mechanical properties of such propellants, especially at temperatures well above ambient temperature, will need careful consideration particularly as an increasing proportion of nitrocellulose binder is replaced by energetic plasticizers and polymers. Softening of the propellant matrix at high temperatures accompanied by nonlinear changes in fracture toughness as a function of temperature (Reference 23) can be expected as proportions of energetic plasticizers and polymers incorporated in the propellant are increased.

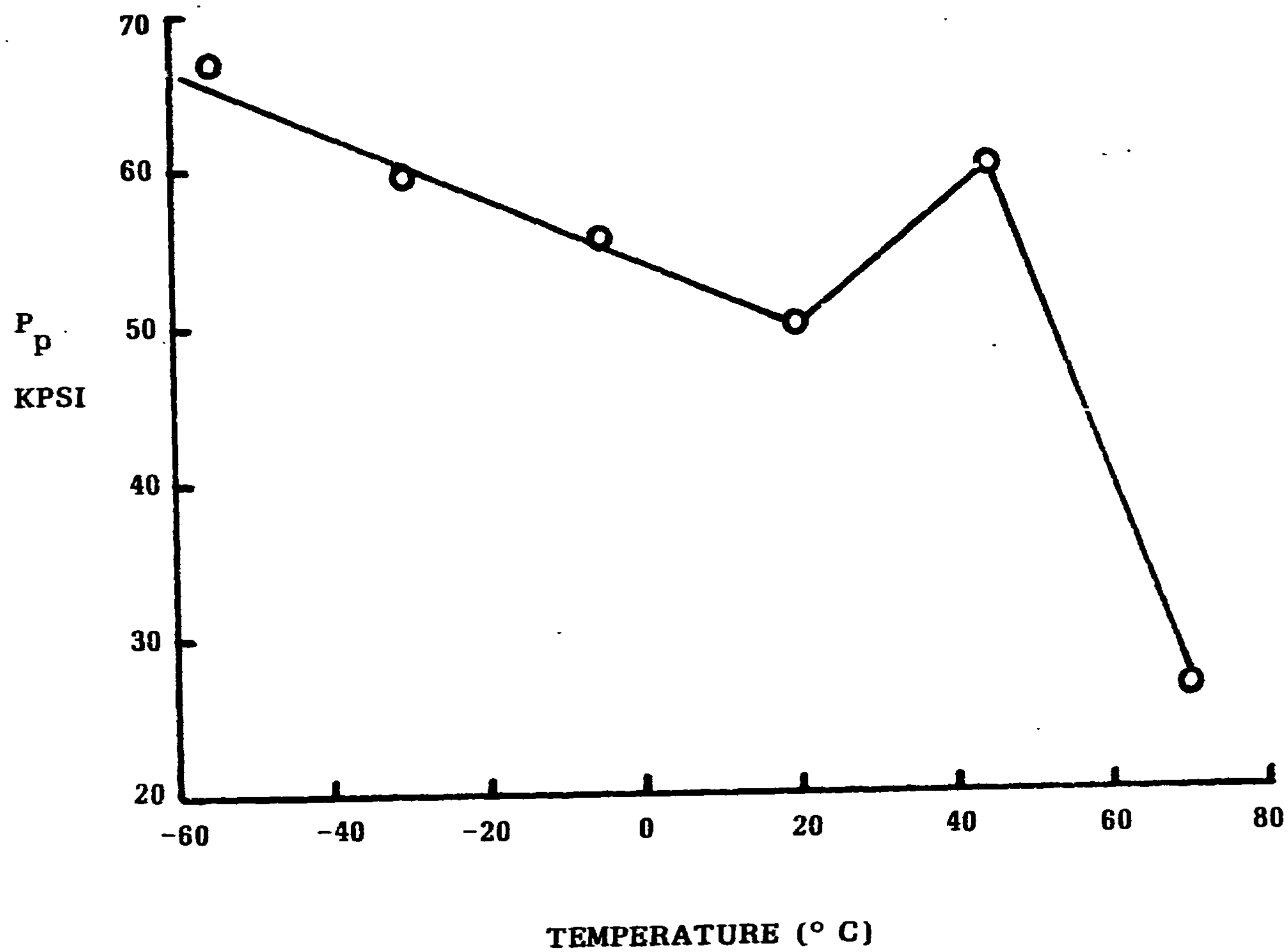

Figure 15. Peak Chamber Pressure Versus Temperature for ButylNENA Propellant at a Full Charge Weight of 132 Grams

SECTION IV

SUMMARY AND CONCLUSIONS

With the exception of GAU-8 extract, all propellants evaluated in the 20-mm and 30-mm guns have displayed anomalously low piezometric efficiencies at low temperatures which can be attributed to brittle grain fracture presumably induced by longitudinal pressure waves set up by the primer blast. Brittle grain fracture at low temperatures becomes more prominent at reduced CW's in the triple base and nitramine propellants. Both the 20-mm ball (WC870) and rolled ball (WC872) propellant show piezometric efficiency anomalies attributable to low temperature brittle grain fracture. The 30-mm rolled ball propellant (WC895) shows similar low temperature grain fracture characteristics.

At higher temperatures though, the rolled ball propellants, WC872 and WC895, as well as the triple base propellant No. 26, show evidence of unusually high piezometric efficiencies. In particular, the rolled ball propellants show a pronounced ballistic insensitivity to temperature effects. Such insensitivity may result from severe low temperature brittle grain fracture, with a lesser and diminishing degree of fracture at ambient temperature and above, until at high temperatures (approximately 60°to 70°C) the increased plasticity of the propellant material resists grain fracture. Hence, at high temperature the grains behave normally and, therefore, show reduced P_p's (or higher piezometric efficiencies).

Another mechanism which can induce anomalously low and high piezometric efficiencies at high temperatures involves a physical softening of the propellant material. Highly plasticized gun propellants (such as the NC/DEGN propellant in the 27-mm aircraft cannon or BuNENA propellant) can display markedly nonlinear behavior between piezometric efficiency and T (or CW) at high temperatures. Such behavior may be attributed to a complex interplay grain deformation and partial closure of the perforations with accompanying reduced gas permeability of the compacted propellant bed induced by the primer blast.

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